Mn-Cr ISOTOPIC SYSTEMATICS OF CHONDRULES FROM THE BISHUNPUR AND CHAINPUR METEORITES. L. Nyquist[1], D. Lindstrom[1], C.-Y. Shih[2], H. Wiesmann[2], D. Mittlefehldt[2], S. Wentworth[2] and R. Martinez[2]; [1]Code SN41, NASA Johnson Space Center, [2]Mail Code C23, Lockheed-Martin Engineering and Sciences Co., 2400 NASA Road 1, Houston, TX 77258.

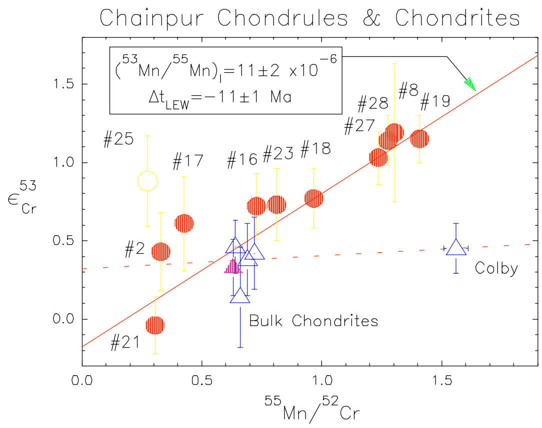

Figure 1. Mn-Cr data for Chainpur chondrules (circles), bulk Chainpur (filled triangle), and other bulk chondrites (open triangles).

We report Mn-Cr data for chondrules from the Bishunpur (LL3.1) and Chainpur (LL3.4) chondrites. Much of the Chainpur data were reported earlier [1]. Fig. 1 includes new data for chondrules #2 and #19, both porphyritic olivine chondrules, expressed in terms of ε^{53}, the deviation of $^{53}Cr/^{52}Cr$ from the terrestrial value in parts in 10^4. The complete data set defines $(^{53}Mn/^{55}Mn)_I = 11\pm2 \times 10^{-6}$, corresponding to a formation interval $\Delta t_{LEW} = -11\pm1$ Ma before formation of the LEW86010 angrite with $(^{53}Mn/^{55}Mn)_{LEW} = 1.44 \times 10^{-6}$ [2]. Alternatively, $\Delta t_{All} = +6.4^{+2.6}_{-3.0}$ Ma relative to $(^{53}Mn/^{55}Mn)_{BR1} = (3.66\pm1.22) \times 10^{-5}$ for the Type B inclusion BR1 [3], within the range of ^{26}Al-^{26}Mg formation times for individual chondrules [1].

The Bishunpur data are shown in Fig. 2. The data for the two meteorites are in good agreement with one another, and with data for bulk chondrites. A linear least squares fit to the Bishunpur data gives an isochron slope of 0.91±0.34 and intercept of -0.16±0.34 corresponding to $(^{53}Mn/^{55}Mn)_I = 10\pm4 \times 10^{-6}$ and $\Delta t_{LEW} = -10.5^{+2.5}_{-1.7}$ Ma, well within error limits of the values for Chainpur. Small differences in ε^{53} values result from using different mass fractionation "laws". For consistency with our earlier data [1,2], we use a modified power law [4] here, but note that the exponential law [5] gives a nearly identical slope of 0.88±0.33, but a lower intercept of -0.52±0.33. The low value of ε^{53} for Bishunpur #11 is preserved when normalized with the exponential law, implying a real effect such as "late" isotopic equilibration or addition of Mn relative to Cr. Variations in age among the chondrules are expected from prior I-Xe studies of Chainpur, Semarkona, and Tieschitz [1].

An ambiguity with regard to interpreting the whole-chondrule isochrons arises from the possibility of correlated production of Mn and Cr isotopes during nucleosynthesis, such that part of the positive correlation of $^{53}Cr/^{52}Cr$ with $^{55}Mn/^{52}Cr$ could arise from mixing of precursor dust components prior to chondrule formation. A plot of $^{54}Cr/^{52}Cr$ and $^{53}Cr/^{52}Cr$ (both expressed in ε-units) for Chainpur chondrules hints at this possibility [1]. The Bishunpur data also hint at such a correlation, but more weakly. Until the issue is resolved, the slopes of the fitted lines in Figs. 1 and 2 are best considered upper limits to those for true isochrons.

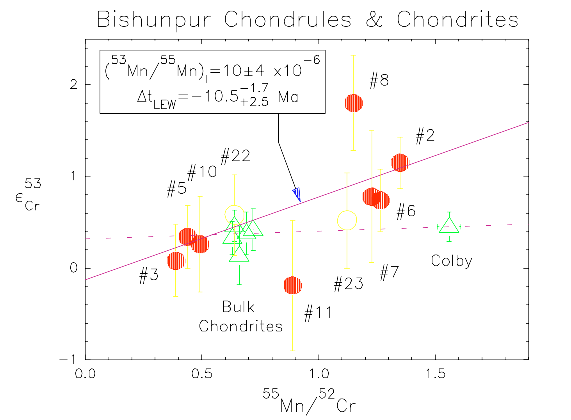

Figure 2. Mn-Cr data for Bishunpur chondrules (filled circles), chondrule fragments (open circles), and other bulk chondrites (open triangles). Fragment #22 is a pyroxene grain, not a chondrule.

Comparison of 50% condensation temperatures at an assumed solar nebula pressure of 10^{-4} atm for Mn, Cr, and Sc to those of Mg, Fe, and Si [6] suggests that early condensing forsterites would be enriched in Sc (most refractory) and depleted in Mn (least refractory), whereas the opposite would be true of mafic silicates condensed later. Cr is slightly more refractory than Mn, so the Mn/Cr ratio in residual materials is expected to increase as condensation proceeds. With the exceptions of radial pyroxene chondrules #2 and #6 and pyroxene fragment #22, those Bishunpur chondrules analyzed for their Cr isotopic compositions have Sc abundances equal to or greater than those of bulk LL chondrules (Sc_{LL}>1). (The chondrules were classified into the textural sub-types of [7] on the basis of SEM/EDX of interior surfaces exposed by breaking them). The porphyritic olivine (PO) chondrules had high Sc and low Mn abundances, as expected for the earliest condensing solids, whereas the porphyritic-olivine-pyroxene (POP) chondrules have Sc abundances approximately equal to those in bulk LL chondrites. The Mn abundances in the majority of the chondrules also exceeded those in bulk LL-chondrites.

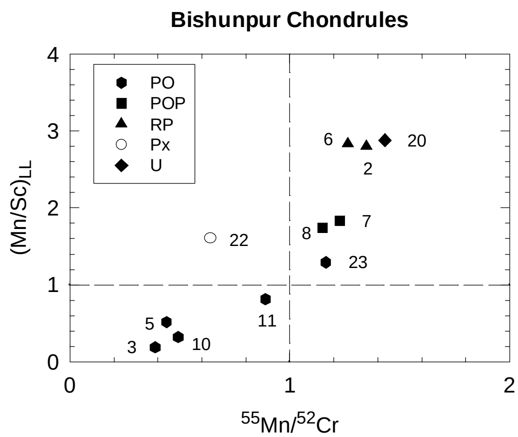

Figure 3. LL-chondrite normalized Mn/Sc ratios for Bishunpur chondrules plotted vs the atomic $^{55}Mn/^{52}Cr$ ratios. U = unclassified.

LL-chondrite normalized $(Sc/Fe)_{LL}$ and $(Mn/Fe)_{LL}$ ratios in the chondrules were >1 with the exceptions of #2, 6, and 22 ($(Sc/Fe)_{LL}$) and #3 ($(Mn/Fe)_{LL}$). Although values of $(Mn/Fe)_{LL}$ >1 are unexpected on the basis of the 50% condensation temperatures, which suggest Mn should be less refractory than Fe, this observation also suggests that the PO chondrules #3, 5, 10, and 11 were enriched in more refractory, early condensed solids, whereas the RP chondrules #2 and #6 contained less refractory, presumably later, materials. That similar relationships were not noted for the Chainpur chondrules may be because most of them included complete rims, which were lacking for many of the Bishunpur chondrules. Fig. 3 plots $(Mn/Sc)_{LL}$ (least refractory/most refractory) versus $^{55}Mn/^{52}Cr$, expressed in "atomic" units for comparison with the isotopic data of Fig. 2. If $(Mn/Sc)_{LL}$ is volatility-controlled, then $^{55}Mn/^{52}Cr$ must be volatility-controlled as well. Note that the relative variation is much larger for $(Mn/Sc)_{LL}$ than for $^{55}Mn/^{52}Cr$, probably because Sc is much more refractory than Cr.

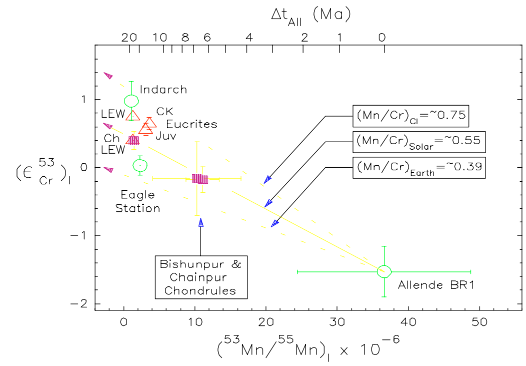

Figure 4. Initial ε^{53} and relative formation age for Bishunpur (larger error bar) and Chainpur (smaller error bar) chondrules compared to values for other meteorites the and

From the above, we conclude that variations in Mn/Cr for these chondrules were established during condensation of solids from the solar nebula. Chondrules are most often interpreted as the result of melting pre-existing solids, and interelement fractionations may have predated chondrule formation [8]. Thus, the "isochrons" of Figs. 1 and 2 may not give the formation time of all of the chondrules analyzed, nor even of any individual chondrule. However, the whole-chondrule isochrons should give an upper limit to the time of chondrule formation, and, perhaps more fundamentally, an estimate of the time when chondrule precursors were condensing from the gaseous solar nebula.

Fig. 4 plots the Mn-Cr formation intervals versus the corresponding values of initial ε^{53}_{I}. The parameters (Δt_{All}, ε^{53}_{I}) correspond well to values expected for radiogenic growth in a solar nebula with $(Mn/Cr)_{Solar}$ = 0.55 ($(^{55}Mn/^{52}Cr)_{Solar}$ = 0.62 [9]), a value in good agreement with the average value for H and L chondrites (see Figs. 1 and 2). Thus, the Mn-Cr systematics of the Bishunpur and Chainpur chondrules are in accord with the Allende measurements. Not surprisingly, the Mn-Cr systematics of these LL chondrules indicate they formed prior to igneous partitioning of Mn and Cr among the minerals in angrites and eucrites [2,10,11].

REFERENCES: [1] Swindle *et al.* (1996) *Chondrules and the Protoplanetary Disk.*Cambridge Univ. Press., 77-86. [2]Nyquist *et al.* (1994) *Meteoritics*, **29**, 872-885.[3] Birck & Allegre (1985) *GRL* **12**, 745-748. [4] Prombo et al. (1989) *Meteoritics*, **24**, 318. [5] Russell et al. (1978) *GCA* **42**, 1075-1090. [6] Wasson (1985) *Meteorites: Their Record of Early Solar-System History.* W. H. Freeman & Co. New York. [7] Gooding & Keil (1981) *Meteoritics*, **16**, 17-43. [8] Grossman (1996) *Chondrules and the Protoplanetary Disk.* Cambridge Univ. Press., 243-253. [9] Anders & Grevasse (1989) *GCA* **53**, 197-214. [10] Lugmair *et al.* (1992) *LPS XXIIII*, 823-824. [11] Lugmair *et al.* (1994) *LPS XXV*, 813-814.